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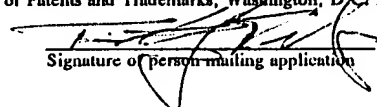
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**APPLICATION FOR LETTERS PATENT**

for

**HONEYCOMB CAPACITOR AND METHOD OF FABRICATION**

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# HONEYCOMB CAPACITOR AND METHOD OF FABRICATION

## BACKGROUND OF THE INVENTION

Field of the Invention: The present invention relates to a semiconductor memory device and method of fabricating same. More particularly, the present invention relates to capacitor fabrication techniques applicable to dynamic random access memories ("DRAMs") capable of achieving an improved degree of integration and <sup>a number of</sup> lower defects within the DRAM.

State of the Art: A widely-utilized DRAM (Dynamic Random Access Memory) manufacturing process utilizes CMOS (<sup>complementary</sup> ~~Complimentary~~ Metal Oxide Semiconductor) technology to produce DRAM circuits which comprise an array of unit memory cells, each including one capacitor and one transistor, such as a field effect transistor ("FET"). In the most common circuit designs, one side of the transistor is connected to external circuit lines called the bit line and the word line, and the other side of the capacitor is connected to a reference voltage that is typically <sup>one-half</sup> ~~1/2~~ the internal circuit voltage. In such memory cells, an electrical signal charge is stored in a storage node of the capacitor connected to the transistor which charges and discharges circuit lines of the capacitor.

Higher performance, lower cost, increased miniaturization of components, and greater packaging density of integrated circuits are ongoing goals of the computer industry. The <sup>advantages</sup> ~~advantage~~ of increased miniaturization of components include: reduced-bulk electronic equipment, improved reliability by reducing the number of solder or plug connections, lower assembly and packaging costs, and improved circuit performance. In pursuit of increased miniaturization, DRAM chips have been continually redesigned to achieved ever-higher degrees of integration which has reduced the size of the DRAM. However, as the dimensions of the DRAM are reduced, the <sup>occupied</sup> ~~occupation~~ area of each unit memory cell of the DRAM must be reduced. This reduction in occupied area necessarily results in a reduction of the dimensions of the

capacitor, which, in turn, makes it difficult to ensure required storage capacitance for transmitting a desired signal without malfunction. However, the ability to densely pack the unit memory cells while maintaining required capacitance levels is a crucial requirement of semiconductor manufacturing technologies if future generations of DRAM devices are to be successfully manufactured.

In order to minimize such a decrease in storage capacitance caused by the reduced occupied area of the capacitor, the capacitor should have a relatively large surface area within the limited region defined on a semiconductor substrate. The drive to produce smaller DRAM circuits has given rise to a great deal of capacitor development. However, for reasons of available capacitance, reliability, and ease of fabrication, most capacitors are stacked capacitors in which the capacitor covers nearly the entire area of a cell and in which vertical portions of the capacitor contribute significantly to the total charge storage capacity. In such designs, the side of the capacitor connected to the transistor is generally called the "storage node" or "storage poly" since the material out of which it is formed is doped polysilicon, while the polysilicon layer defining the side of the capacitor connected to the reference voltage mentioned above is called the "cell poly."

An article by J. H. Ahn et al., entitled "Micro Villus Patterning (MVP) Technology for 256 Mb DRAM Stack Cell," 1992 IEEE, 1992 Symposium on VLSI Technology Digest of Technical Papers, pp. 12-13, hereby incorporated herein by reference, discusses the use of MVP (Micro Villus Patterning) technology for forming a high surface area capacitor. FIGs. 25-28 illustrate cross-sectional views of this technique. FIG. 25 shows a memory cell structure comprising a substrate 202 which has been oxidized to form thick field oxide areas 204 with transistor gate members 206 disposed on the surface of the substrate 202. A barrier layer 208 is disposed over the transistor gate members 206, substrate 202, and field oxide areas 204, and a silicon nitride layer 210 is disposed over the barrier layer 208. A storage poly 212 is disposed on the silicon nitride layer 210 and extends through the silicon nitride layer 210 and the

barrier layer 208 and between two transistor gate members 206 to contact the substrate 202. A layer of silicon dioxide 214 is disposed over the storage poly 212.

As shown in FIG. 26, an HSG (HemiSpherical-Grain) polysilicon layer 216 is grown on the exposed surfaces of the silicon nitride layer 210, the storage poly 212, and the silicon dioxide layer 214. The structure is then etched using the HSG polysilicon layer 216 as a mask which results in very thin, closely spaced micro villus bars or pins 218, as shown in FIG. 27. The silicon dioxide layer 214 and the silicon nitride layer 210 are then stripped to form the structure shown in FIG. 28. A finalized capacitor would be formed by further processing steps including depositing a dielectric layer on the etched storage poly and depositing a cell poly on the dielectric layer.

Although the MVP technique greatly increases the surface area of the storage poly, a drawback of using the MVP technique is that it can result in splintering problems (or slivers) in the storage node cell poly. As illustrated in FIG. 29, the micro villus bars/pins 218, formed in the method shown in FIGs. 25-28, are thin and fragile such that they are susceptible to splintering that may result in one or more of the micro villus bars/pins (such as pin 220) falling over and shorting to an adjacent storage poly 222, which would render the adjacent storage cells shorted and unusable.

In a 64M DRAM, for example, even if there <sup>was</sup> ~~were~~ only one out of 100,000 cells that had a failure due to a splintered macro villus bar/pin shorting with an adjacent storage cell, it would result in 640 failures or shorts in the DRAM. Generally, there are a limited number of redundant memory cells (usually less than 640 in a 64M DRAM) within a DRAM which are available for use in place of the shorted memory cell. Thus, if the number of failures exceeds the number of redundant memory cells within the DRAM, the DRAM would have to be scrapped.

Therefore, it would be desirable to increase storage cell capacitance by using a technology such as MVP while eliminating polysilicon storage node splintering problems.

## SUMMARY OF THE INVENTION

5 The present invention relates to a method of forming a high surface area capacitor, generally used in DRAMs. The present invention takes an opposite approach from the prior art in forming capacitors. Rather than forming bars or pins to increase the surface area, the present invention forms the opposite by etching holes or voids into the storage poly to form a honeycomb or webbed structure. Such a honeycomb/webbed structure forms a high surface area capacitor without bars or pins which could splinter and short out an adjacent storage cells, as discussed above.

10 Numerous methods could be employed to achieve the honeycomb structure of the present invention. One such method is a reverse MVP technique wherein an HSG polysilicon layer is grown on the surface of the storage poly and a mask layer is deposited over the HSG polysilicon layer. An upper portion of the mask layer is then removed forming micro openings to expose the <sup>uppermost</sup> ~~uppermost~~ portions of the HSG polysilicon layer. The exposed HSG polysilicon layer portions are then etched, which translates the pattern of the exposed HSG polysilicon layer portions (which is generally the reverse pattern of the bars or pins which would be formed by the prior art method) into the storage poly. The capacitor is completed by depositing a dielectric material layer over the storage poly layer and depositing a cell poly layer over the dielectric material layer.

## BRIEF DESCRIPTION OF THE DRAWINGS

20 While the specification concludes with claims particularly pointing out and distinctly claiming that which is regarded as the present invention, the advantages of this invention can be more readily ascertained from the following description of the invention when read in conjunction with the accompanying drawings in which:

25 FIGs. 1-10 are side cross-sectional views of a method of forming a memory cell capacitor according to the present invention;

FIGs. 11-21 are side cross-sectional views of an alternate technique of forming a memory cell capacitor according to the present invention;

FIG. 22 is an illustration of a scanning electron micrograph of an oblique view of a storage poly after etching in the formation of a capacitor according to the present invention;

FIG. 23 is an illustration of a scanning electron micrograph of a side cross-sectional view of a storage poly after etching in the formation of a capacitor according to the present invention;

FIG. 24 illustrates an oblique, cross-sectional view of FIG. 21;

FIGs. 25-28 are side cross-sectional views of a prior art MVP technique of forming a capacitor ~~by an MVP technique~~; and

FIG. 29 is a side cross-sectional view of a prior art capacitor formed by an MVP technique which illustrates the problem of storage node splintering.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGs. 1-10 illustrate a technique according to the present invention for forming a capacitor for a memory cell. It should be understood that the figures presented in conjunction with this description (with the exception of FIGs. 22 and 23) are not meant to be actual cross-sectional views of any particular portion of an actual semiconducting device, but are merely idealized representations which are employed to more clearly and fully depict the process of the invention than would otherwise be possible. FIG. 1 illustrates an intermediate structure 100 in the production of a memory cell. This intermediate structure 100 comprises a semiconductor substrate 102, such as a lightly doped P-type crystal silicon substrate, which has been oxidized to form thick field oxide areas 104 and exposed to implantation processes to form drain regions 106 and source regions 107. Transistor gate members 108 are formed on the surface of the semiconductor substrate 102, including the gate members 108 residing on a substrate active area 118 spanned between the drain regions 106 and the source regions 107.

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The transistor gate members 108 each comprise a lower buffer layer 110, preferably silicon dioxide, separating a gate conducting layer or ~~wordline~~<sup>word line</sup> 112 of the transistor gate member 108 from the semiconductor substrate 102. Transistor insulating spacer members 114, preferably silicon dioxide, are formed on either side of each transistor gate member 108 and a cap insulator 116, also preferably silicon dioxide, is formed on the top of each transistor gate member 108. A barrier layer 119, preferably silicon dioxide, is disposed over the semiconductor substrate 102, the thick field oxide areas 104, and the transistor gate members 108, and etched to expose the drain regions 106 on the semiconductor substrate 102. A storage poly 120, such as a polysilicon material, is deposited over the transistor gate members 108, the semiconductor substrate 102, and the thick field oxide areas 104.

An HSG (HemiSpherical-Grain) polysilicon layer 122 is grown on the surface of the storage poly 120, as shown in FIG. 2 (which is an enlarged view of the surface of the storage poly 120). Preferably, the HSG polysilicon layer 122 is grown by applying a layer of amorphous silicon over the storage poly 120. A polysilicon seed crystal layer is applied at a temperature of at least 500°C, preferably between about 550 and 600°C, and a pressure between about  $10^{-7}$  and  $10^{-2}$  Torr. The polysilicon seed crystal layer is then annealed at a temperature of at least 500°C, preferably between about 550 and 700°C, and a pressure between about  $10^{-7}$  and  $10^{-2}$  Torr. The annealing causes the amorphous silicon to nucleate into a polysilicon material around the polysilicon seed crystal to form the HSG polysilicon layer 122. The grain size of the HSG polysilicon should be at least 350Å, preferably between about 700 and 1000Å. The HSG polysilicon formation process can be accomplished in batch (multi-wafer) or single wafer equipment.

A mask layer 124, preferably silicon dioxide with a thickness of about 350 angstroms, is deposited over the HSG polysilicon layer 122, as shown in FIG. 3. An upper portion of the mask layer 124 is then removed, preferably facet etched (dry etching, sputter etching, and planarization may also be used), to form micro openings

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to expose the <sup>uppermost</sup>~~uppermost~~ portions 126 of the HSG polysilicon layer 122, as shown in FIG. 4. Preferably, about 50 to 75% of the HSG polysilicon layer 122 will be exposed. As shown in FIG. 5, a photo-resist material 128 is then deposited to pattern a desired position of the memory cell capacitor (the HSG polysilicon layer 122 and the mask layer 124 are shown as a single layer 130).

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As shown in FIG. 6, a portion of the single layer 130 and a portion of the storage poly 120 are etched to expose a portion of the barrier layer 119 over the source region 107, the thick field oxide 104, and a portion of the gate members 108. The photo-resist material 128 is then removed.

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The exposed <sup>uppermost</sup>~~uppermost~~ HSG polysilicon layer portions 126 are then etched <sup>by</sup>~~with~~ a dry anisotropic etch, with an etchant which is highly selective to the mask layer 124, preferably selective at a ratio of about 70:1 or higher, as shown in progress in FIG. 8. A preferred selective etch chemistry would contain chlorine gas as the primary etchant with passivation for the barrier layer 119 (silicon dioxide) <sup>being</sup>~~is~~ hydrogen bromide gas (i.e., the hydrogen bromide prevents the etching of the silicon dioxide barrier layer 119 which, in turn, prevents the source region 107 from being etched). Selective etching is the use of particular etchants which etch only a particular material or materials while being substantially inert to other materials.

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The etching translates the pattern of the exposed <sup>uppermost</sup>~~uppermost~~ HSG polysilicon layer portions 126 into the storage poly 120. Any remaining mask layer material 124 is then removed, preferably by a wet or in situ etch. The etching of the storage poly 120 results in an etched structure 132 having convoluted openings 134, shown with the convoluted openings 134 greatly exaggerated in FIG. 9. Capacitors 136 are completed by depositing a dielectric material layer 138 over the etched structure 132 and depositing a cell poly layer 140 over the dielectric material layer 138, such as shown in FIG. 10.

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It is, of course, understood that the present invention is not limited to any single technique forming the memory cell capacitor. For example, FIGs. 11-21 illustrate an



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alternate memory cell capacitor formation technique. Elements common to both FIGs. 1-10 and FIGs. 11-21 retain the same numeric designation. FIG. 11 shows a first barrier layer 142, preferably tetraethyl orthosilicate - TEOS, disposed over the semiconductor substrate 102, the thick field oxide areas 104, and the transistor gate members 108. The transistor gate members 108 each comprise a lower buffer layer 109, preferably silicon dioxide or silicon nitride, separating the gate conducting layer or <sup>word line</sup> ~~wordline~~ 112 of the transistor gate member 108 from the semiconductor substrate 102. Transistor insulating spacer members 113, made of silicon nitride, are formed on either side of each transistor gate member 108 and a cap insulator 115, also made of silicon nitride, is formed on the top of each transistor gate member 108. Preferably, the gate members 108 residing on the thick field oxide areas 104 abut the active area 118 which will protect the thick field oxide areas 104 during subsequent etching. A second barrier layer 144 (preferably made of borophosphosilicate glass - BPSG, phosphosilicate glass - PSG, or the like) is deposited over the first barrier layer 142, as shown in FIG. 12.

It is, of course, understood that a single barrier layer could be employed. However, a typical barrier configuration is a layer of TEOS over the transistor gate members 108 and the substrate 102 followed by a BPSG layer over the TEOS layer. The TEOS layer is applied to prevent dopant migration. The BPSG layer contains boron and phosphorus which can migrate into the source and drain regions formed on the substrate during inherent device fabrication heating steps. This migration of boron and phosphorus can change the dopant concentrations in the source and drain regions which can adversely affect the performance of the memory cell.

As shown in FIG. 13, a resist material 146 is patterned on the second barrier layer 144, such that predetermined areas of the memory cell capacitor formation will be etched. The second barrier layer 144 and the first barrier layer 142 are etched to exposed a portion of the semiconductor substrate 102, as shown in FIG. 14. The transistor insulating spacer members 113 and the cap insulator 115 each being made of

silicon nitride resists the etchant and thus prevents shorting between the word line 112 and the capacitor to be formed. The resist material 146 is then removed, as shown in FIG. 15, and a layer of amorphous silicon 148, which upon subsequent annealing will become polysilicon, is then applied over second barrier layer 144 to make contact with the semiconductor substrate 102, as shown in FIG. 16. The amorphous silicon layer 148 is then planarized down to the second barrier layer 144 to form silicon plugs 150, as shown in FIG 17. The planarization is preferably performed using a mechanical abrasion, such as a chemical mechanical planarization (CMP) process.

An HSG polysilicon layer 122 is selectively grown on the surface of the silicon plugs 150, as shown in FIG. 18. The <sup>selective</sup> ~~selectively~~ growth of the HSG polysilicon layer 122 is preferably achieved by applying a polysilicon seed crystal layer over the second barrier layer 144 and the silicon plugs 150. The polysilicon seed crystal layer is applied at a temperature of at least 500°C, preferably between about 550 and 600°C, and a pressure between about 10<sup>-7</sup> and 10<sup>-2</sup> Torr. The polysilicon seed crystal layer is then annealed at a temperature of at least 500°C, preferably between about 550 and 700°C, and a pressure between about 10<sup>-7</sup> and 10<sup>-2</sup> Torr. The selectivity of growth of the HSG polysilicon layer 122 is due to the difference in incubation times required to seed nucleation sites for the HSG polysilicon layer 122 on the silicon plugs 150 (amorphous silicon) and the second barrier layer 144. The HSG nucleation sites form more quickly on the silicon plugs 150 than on the second barrier layer 144. Thus, the HSG polysilicon growth can be completed on the silicon plugs 150 and the formation halted prior to the formation of HSG polysilicon on the second barrier layer 144.

A mask layer 124 is deposited over the HSG polysilicon layer 122. The upper portion of the mask layer 124 is then removed to expose the <sup>upper-most</sup> ~~upper-most~~ portions 126 of the HSG polysilicon layer 122, as shown in FIG. 20. The exposed HSG polysilicon layer portions 126 are then etched, as previously shown in FIG. 8. The etching of the silicon plugs 150 results in an etched structure 152 having convoluted openings 154, shown with the convoluted openings 154 greatly exaggerated in FIG. 21. The memory

cell capacitors are completed by depositing a dielectric material layer over the etched structure 152 and depositing a cell poly layer over the dielectric material layer, as previously described for FIG. 10.

The method of the present invention results in a unique honeycomb storage poly structure such that the storage poly has a highly webbed structure rather than free standing micro villus bar/pin structures, as discussed above. This webbed structure is essentially a substantially continuous, convoluted maze-like structure defined by a plurality of interconnected wells extending in various directions in the X-Y plane. In other words, the maze-like structure extends in the X, Y, and Z coordinates, rather than essentially only in the Z coordinate in which a free-standing micro villus bar/pin structure with limited extent in the X-Y plane would essentially only exist. An exemplary illustration of a typical pattern in the X-Y plane is shown in FIG. 22.

FIG. 22 is an illustration of a scanning electron micrograph, top view, of the etched structure 132 or 152 after etching same and after removal of any remaining mask layer material 124. As FIG. 22 illustrates, the etched structure 132, 152 is highly integrated/webbed. Another way to visualize the resulting structure is in terms of canyons and holes between interconnected mesas or ridges defining a convoluted topography.

The integrated/webbed structure of the storage poly 120 in the X and Z coordinate is shown in FIG. 23. FIG. 23 is an illustration of a scanning electron micrograph, side cross-sectional view, of the storage poly. FIG. 24 illustrates an oblique, cross-sectional view of the etched structure 152 of FIG. 21. This maze-like webbed structure is substantially self-buttressing. In other words, the convoluted and webbed shape forms a strong structure which allows the capacitor to withstand forces which would otherwise splinter a micro villus pin/bar capacitor.

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Having thus described in detail preferred embodiments of the present invention, it is to be understood that the invention defined by the appended claims is not to be limited by particular details set forth in the above description as many apparent variations thereof are possible without departing from the spirit or scope thereof.